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PHASE-COHERENT ASTROMETRIC INTERFEROMETRY(U)  
MASSACHUSETTS INST OF TECH CAMBRIDGE RESEARCH LAB OF  
ELECTRONICS D H STAELIN ET AL 17 AUG 87  
N00014-86-C-2114

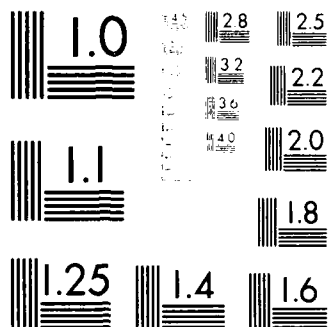
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ANNUAL REPORT

Phase-Coherent Astrometric Interferometry

Naval Research Laboratory

Contract N00014-86-C-2114

Covering the period

1 February 1986 - 31 January 1987

Submitted by

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17 August 1987

Massachusetts Institute of Technology  
Research Laboratory of Electronics  
Cambridge, Massachusetts 02139

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

ADA184428

## REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION		1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION/AVAILABILITY OF REPORT	
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE		Approved for public release; distribution unlimited	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)		5. MONITORING ORGANIZATION REPORT NUMBER(S)	
6a. NAME OF PERFORMING ORGANIZATION Research Laboratory of Electronics Massachusetts Institute of Technology		6b. OFFICE SYMBOL (If applicable)	
7a. NAME OF MONITORING ORGANIZATION Office of Naval Research Massachusetts Institute of Technology		7b. ADDRESS (City, State and ZIP Code) E19-628 Cambridge, MA 02139	
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Naval Research Laboratory		8b. OFFICE SYMBOL (If applicable)	
9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N00014-86-C-2114		10. SOURCE OF FUNDING NOS.	
11. TITLE (Include Security Classification) Code 1234. RD Phase Coherent Astrometric Interferometry		PROGRAM ELEMENT NO. PROJECT NO. TASK NO. WORK UNIT NO.	
12. PERSONAL AUTHOR(S) David H. Staelin		41-0260-86	
13a. TYPE OF REPORT Annual Report		13b. TIME COVERED FROM 2/1/86 TO 1/31/87	
14. DATE OF REPORT (Yr., Mo., Day) 17 August 1987		15. PAGE COUNT 8	
16. SUPPLEMENTARY NOTATION			
17. COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB. GR.	
19. ABSTRACT (Continue on reverse if necessary and identify by block number)			
Work by D. H. Staelin and his collaborators is summarized here.			
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT <input type="checkbox"/> OTIC USERS <input type="checkbox"/>		21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Kyra M. Hall RLE Contract Reports		22b. TELEPHONE NUMBER (Include Area Code) (617)253-2569	
		22c. OFFICE SYMBOL	

### Phase-Coherent Astrometric Interferometer

This year involved continuation of the development of the Mark III stellar interferometer, which is a fringe-tracking long-baseline Michelson interferometer designed primarily for wide-angle astrometry at the milli-arcsecond level. It also is useful for measuring stellar diameters and as an initial test bed for concepts relevant to aperture synthesis imaging. It is being constructed on Mount Wilson, California, as a joint project involving the Massachusetts Institute of Technology, the Smithsonian Astrophysical Observatory, the Naval Research Laboratory, and the U.S. Naval Observatory. The first successful observations with the Mark III occurred during 1986.

Progress continued in the area of instrument development. Our major effort this year has involved the laser siderostat subsystem. This task involved testing and improvement of the laser interferometer's electronics, which had been constructed previously at the Naval Research Laboratory. Modifications were made to the timing circuitry for the interface to the IBM computer, and to the wiring.

Modifications were also made to the motor pulse-generator board, which drives the siderostat stepper motors. The initial motors were replaced with high resolution units. This led to additional changes in a number of related subsystems.

Development of the laser subsystem began during the summer, during which time the initial assembly, system integration, and testing of the Mark III were also supported. The siderostat control system was upgraded so that it could update the 8-parameter siderostat model in real time. This involved adapting the existing off-line Kalman filters to function as a real-time task which is executed every 30 seconds. The Kalman filter was improved during this effort.



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Another effort involved expansion of the system for use with 3 siderostats: this included expansion of the system state description and interfacing the system with the various computers, communication channels, and related system elements. The fringe-tracking and star-tracking logic was also improved and expanded as part of this effort, and documentation for the siderostat system was greatly improved.

Additional tasks performed in the development of the laser siderostat system involved electrical design and construction, optical and mechanical design and construction, theoretical studies related to optimum estimation of siderostat pointing parameters, and related system software development. A complete vacuum system was also designed, assembled, and shipped to Mount Wilson Observatory; it services both delay line vacuum tanks.

Four papers were prepared for publication during this period. Abstracts for these manuscripts are attached; these manuscripts include:

- 1) "Application of Interferometry to Optical Astrometry," M. Shao, M. Colavita, D. H. Staelin, K. J. Johnston, R. S. Simon, J. A. Hughes, and J. L. Hershey.
- 2) "The Mark III Stellar Interferometer," M. Shao, M. M. Colavita, B. E. Hines, D. H. Staelin, D. J. Hutter, K. J. Johnston, D. Mozurkewich, R. S. Simon, J. L. Hershey, J. A. Hughes, and G. H. Kaplan, submitted to Astronomy and Astrophysics, May 1987.
- 3) "Atmospheric Phase Measurements with the Mark III Stellar Interferometer," M. M. Colavita, M. Shao, and D. H. Staelin, submitted to Applied Optics, June 1987.
- 4) "The Two-Color Method for Optical Astrometry: Theory and Preliminary Measurements with the Mark III Stellar Interferometer," M. M. Colavita, M. Shao, and D. H. Staelin, submitted to Applied Optics, June 1987.

# APPLICATION OF INTERFEROMETRY TO OPTICAL ASTROMETRY

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## ABSTRACT

An optical interferometer capable of tracking phase and measuring fringe visibility has demonstrated the ability to measure the precise positions of stars over large angles. This instrument has tracked phase over periods of many hours while switching sequentially among several stars. The 3.1 meter separation of the siderostats has been measured to an accuracy of 50 microns, indicating positional accuracies of three arc seconds. The formal error of the least-squares solution for the baselines is of the order of a micron. The major limitations to accuracy were thermal instabilities and unmonitored siderostat positions. With improvements this technique should be capable of astrometric accuracies exceeding one-hundredth of an arc second.

## I. INTRODUCTION

Since Fizeau first pointed out the possibility of using interferometers in astronomy in 1862 (Muller), astronomers have sought to use interferometry to overcome the limits on optical resolution set by

The Mark III stellar interferometer

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Running title: The Mark III stellar interferometer

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Thesaurus codes

01.04.1 Astrometry

09.04.1 Interferometry

19.03.1 Seeing

19.30.1 Stars, Diameters of

09.03.1 Instruments

06.01.1 Fundamental Stars and Other Objects

Section: Instrumentation

Main Journal



Summary. The Mark III interferometer is an operational long baseline stellar interferometer on Mt. Wilson with four possible baseline configurations from 9 meters NE-SW to 20 meters N-S. The interferometer was designed to be a highly automated astronomical instrument to measure stellar positions and diameters to a magnitude limit of seven. Initial fringe observations were made in September 1986 with a 12-meter N-S baseline. In the following months, semi-automated astrometric and stellar diameter measurements were also made. This paper describes the hardware and software components of the instrument and its operational characteristics.

The interferometer has several novel features. One is the use of optimal estimation and control algorithms (e.g. Kalman filters) in the control loops. Another is the ability to operate both as a closed-loop phased interferometer and eventually as an open-loop or absolute coherent interferometer. High thermal stability and mechanical accuracy should permit the instrument to point blind at an astronomical object and maintain optical path equality to within the limits set by the atmosphere. In this absolute interferometric mode of operation, it should be possible to observe faint astronomical objects that are too dim for phase tracking. In theory, measurements of amplitude, group delay, and closure phase will be possible to 14 mag.

Key words: stellar interferometry, astrometry, stellar diameters, optical array, proper motion

THE TWO-COLOR METHOD FOR OPTICAL ASTROMETRY:  
THEORY AND PRELIMINARY MEASUREMENTS WITH THE  
MARK III STELLAR INTERFEROMETER

M. Mark Colavita and Michael Shao  
Smithsonian Astrophysical Observatory

and

David H. Staelin  
Massachusetts Institute of Technology

The Two-Color Method for Optical Astrometry:  
Theory and Preliminary Measurements with the  
Mark III Stellar Interferometer

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Smithsonian Astrophysical Observatory  
Cambridge, MA  
David H. Staelin  
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**Abstract:** The two-color method for interferometric astrometry provides a means of reducing the error in a stellar position measurement attributable to atmospheric turbulence. The primary limitation of the method is shown to be turbulent water vapor fluctuations, which limit the amount of improvement over a one-color measurement obtainable with a two-color estimate. Secondary atmospheric effects caused by diffraction from small refractive index inhomogeneities and differential refraction for the observation of stars away from zenith are shown to introduce errors that behave as white noise and which should usually not be significant. Other potential error sources due to photon noise, systematic instrumental effects, and imperfect data reduction are also considered. The improvement in accuracy possible with the two-color method is estimated as a factor of 5-10 over the corresponding one-color measurement. Some preliminary two-color measurements with the Mark III stellar interferometer at Mt. Wilson are presented which demonstrate approximately a factor of 5 reduction in the amplitude of the atmospheric fluctuations in a stellar position measurement.

ATMOSPHERIC PHASE MEASUREMENTS  
WITH THE MARK III STELLAR INTERFEROMETER

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Atmospheric Phase Measurements  
with the Mark III Stellar Interferometer

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**Abstract:** The Mark III interferometer is a phase-coherent stellar interferometer designed for astrometry. Operating through the turbulent atmosphere, the instrument is also a sensitive detector of atmospheric phase fluctuations. The effect of phase fluctuations on astrometric accuracy is reviewed, and phase measurements obtained with the instrument at Mt. Wilson using a 12-m baseline are presented. These measurements agree well with the predictions of a simple Kolmogorov spatial spectrum over the frequency range of 0.001 to 100 Hz. From these measurements, the outer scale of turbulence for propagation through the entire atmosphere is estimated to be greater than 2 km. The standard deviation for an absolute astrometric measurement estimated from these measurements is approximately  $0.14T^{-1/6}$  arc sec for long integration times for conditions of 0.5-arc-sec seeing. For star-switched relative measurements, this error should decrease as the square root of the number of switching cycles.

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Contracting Officer's Technical Representative K. J. Johnston Naval Research Laboratory 4555 Overlook Avenue, S.W. Washington, D.C. 20375 - 5000 Contract No. N00014-86-C-2114 Attn: Code 4130	(2)
Administrative Contracting Officer Office of Naval Research E19-628 Massachusetts Institute of Technology Cambridge, MA 02139	(1)
Director, Naval Research Laboratory Code 2627 Washington, D.C. 20375	(6)
Defense Technical Information Center Bldg. 5, Cameron Station Alexandria, Virginia 22314	(12)

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